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Climate and soil requirements for economically important crops in Canada

Canada

Climate and soil requirements for economically important crops in Canada

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3 Editors' note. Raspberries are discussed as one unit, and remaining species of *Rubus*, constituting the blackberries and dewberries, are discussed with *Ribes*. The red raspberry, *R. idaeus*, is predominant in Canada, but black raspberries (*R. occidentalis* L.) and purple raspberries (*R. idaeus* X *R. occidentalis*) are also encountered. Blackberries are derived from several species of *Rubus* and cultivars are rarely identifiable in terms of species composition. Currants and gooseberries are climatically hardier than raspberries and blackberries, but in other respects are fairly similar in terms of cultural requirements. Red and white currants are derived predominantly from two species commonly known as *R. sativum* (Rchb.) Syme and *R. rubrum* L. (names which are currently controversial with regard to their application); often hybrids of the two species are involved and identification to species is problemetical. Black currants belong to *R. nigrum* L. Gooseberries grown in Canada are primarily the hybrid product of *R. uva-crispa* L. and *R. hirtellum* Michx., but occasionally more or less exclusively represent germ plasm of the former species.

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4 Buckwheat is sometimes considered to be a cereal, although it is not a member of the grass family.

PREFACE

This report is one of many activities of the Land Evaluation program of the Land Resource Research Institute, Agriculture Canada. Land evaluation is the procedure of interpreting basic inventories of soils, climate and other environmental variables in an effort to i) indicate possible land use alternatives, ii) indicate the relative worth, utility or importance of allocating a particular use, as opposed to all others, to a given area.

Many steps and considerable knowledge are involved in deciding how land might be allocated. The nature of the physical environment, soils and climate, and the adaptability of plants to this environment are fundamental to wise land use decisions. Under Canadian conditions it is well known that not all crops can be grown in all areas, nor will any one crop perform equally well in all areas.

Over the years much information has been compiled by many researchers on the light, heat, water and soil requirements of crops. These data, although available, are scattered through innumerable scientific journals and reports and are not easily accessed. A search through the entire literature is necessary each time that a given crop is evaluated.

This report pulls together available information on the topic in one, handy reference manual. Approximately two thousand references were reviewed, out of which 169 were selected for this publication. Data are provided for 65 crops, assembled into 9 phenological groups. References are provided for each crop.

This report, although very useful for agricultural land evaluation, has application in many subject areas. Agronomists, plant physiologists, extension workers, crop modellers and teachers, as well as soil scientists and planners will find it a useful reference in their work.

INTRODUCTION AND METHODOLOGY

This report summarizes the climate and soil requirements of the major, economically important crops in Canada. It was compiled through an extensive search of the literature, using the services of Biological Abstracts Reviews, Science Citation and Source Index, and Agricola. Also various books, government reports, bulletins and announcements on agricultural crops were examined. Approximately 2000 references were reviewed, and 169 selected for the report. Those not selected reported research work that was too specific or detailed to have application in field crops production.

The report gives detailed descriptions of the light, heat, water and soil requirements of each crop, in so far as these data are available from the literature. Specific requirements at various phenological growth stages are also reported. References for the information presented for each crop are given and listed in the bibliography at the end of the report.

This report lists the environmental (field) conditions necessary for the successful, long term cultivation of given crops. It is intended as a reference manual for those evaluating or recommending particular crops under given conditions of climate and soil. Crop management requirements, however, are not listed, and the reader is refered to other sources for this information.

FORAGE CROPS - GRASSES

AGROSTIS spp. -- bentgrass; *A. GIGANTEA* Roth -- red top

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: The cool season perennials grown in Canada resume growth at 2-3°C. They are suited to areas where low winter temperatures at ground level are not severe. They do well in Eastern Canada in areas of good snow cover, and are well adapted to the mild winters along the Pacific coast.

WATER: Bentgrass tolerates dry and wet summer conditions.

SOIL: The best yields are obtained on loamy, near-neutral and well drained soils, but the plants can be grown on a variety of soils. Unlike many other grasses the plants can survive reasonably well on infertile, acidic and poorly drained soils, but yields are reduced considerably.

GENERAL: Due to its rooting pattern, this plant can be used to stabilize sandy soils. Three species and commonly grown in Canada, *A. stolonifera* L., creeping bent, *A. tenuis* sibth., colonial bent, and *A. canina* L., velvet bent.

REFERENCES: 120, 129, 144, 150, 157

PHALARIS ARUNDINACEA L. -- reed canary grass

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This is a winter-hardy perennial that grows well in cool, wet growing conditions. It resumes growth at 2-3°C. Good snow cover in eastern Canada and southwest B.C. provides adequate protection even when temperatures reach -35°C. The crop does not survive in the dry highlands of the Prairies, due to thin snow cover and severe cold and windy weather. Occasional high summer temperatures (45°C) can be tolerated.

WATER: Reed canary grass grows well on poorly drained soils, and also on well drained land if rainfall during the growing season is greater than 50 cm or the water table remains high until mid-summer. The plant is resistant to drought.

SOIL: Excellent production is achieved on loamy or heavy soils with high water tables. This grass grows successfully on sandy soils with high organic matter contents and adequate rainfall. It is well suited for lowlands that are frequently inundated in the spring, as well as occasionally in the summer. It can tolerate an immersion period as long as 4-5 weeks if the leaves are above water level. The crop requires an acid to weak alkaline soil with adequate fertility, and periodic good drainage.

REFERENCES: 96, 129, 130, 135, 139, 144, 154, 157

BROMUS INERMIS Leyss. -- brome, bromegrass, chess

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This perennial is well suited to a cool, wet climate, resumes growth at 2-3°C, and is tolerant of severe winter conditions (the "northern brome" type more suitable than the "southern brome" type). It is resistant to heat and drought.

WATER: Maximum production is achieved in a wet climate.

SOIL: Brome grass can be grown on many soil types but production is best on deep loams with good to excellant drainage. It requires highly fertile soils, especially those rich in nitrogen, and pH should be between 6.0 and 8.0.

GENERAL: Brome grass grows better on sandy soil than timothy, and tolerates wet areas better than orchard-grass. Loams and sandy loams within the Dark Brown soils in western Canada are best suited for seed production.

REFERENCES: 96, 120, 129, 130, 135, 142, 154, 157

DACTYLIS GLOMERATA L. -- orchard grass

LIGHT: Long days are required to initiate flowering.

TEMPERATURE: Orchard grass is a cool season crop, resuming growth at 2-3°C and attaining an optimum growth rate at temperatures between 14° and 18°C. Higher temperatures inhibit flowering. It has limited adaptability to winter conditions (mild winter conditions or thick snow cover reduce winterkilling). Orchard grass is less winter hardy than timothy.

WATER: Maximum yields are obtained in areas receiving 50-60 cm of rainfall during the growing season. Orchard grass is more resistant to drought than timothy, and is suited to light soils with low water retention.

SOIL: The best growth is obtained on fertile, well drained loam soils. Yearly applications of nitrogen are recommended, particularly on sandy soils. Soil pH should be between 5.0 to 8.0, with an optimum of 6.0-7.0.

REFERENCES: 51, 52, 96, 120, 135, 144, 154, 157

ELYMUS JUNCEUS Fisch. -- Russian wildrye

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This is a perennial which resumes growth at 2-3°C and is very resistant to drought and cold. It appears to be suited to a wide range of climatic conditions, but information on this topic is limited.

WATER: Lyme-grass is well adapted to semi-arid areas and cool areas with low rainfall levels. It requires a good supply of soil moisture at the seedling stage due to the slow growth rate of the root system.

SOIL: Lyme-grass is well suited to the loams and heavy soils of the Prairies and to semi-arid areas in British Columbia. It can be grown on dry and sandy soils if there is adequate moisture at the seedling stage. It is tolerant of alkaline soils.

GENERAL: This plant is native to semi-arid areas of Siberia, Russia and Central Asia.

REFERENCE: 146

FESTUCA SPP. -- fescue

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This is a cool season perennial which resumes growth at 4-5°C, with some slow growth at 2°C. It is more winter hardy than orchard grass but less so than timothy.

WATER: Good production is achieved under humid conditions, but it shows reasonable tolerance to drought.

SOIL: Excellent growth can be achieved on fertile soils, preferably loams to heavy clays with adequate moisture. Good growth is obtainable on sandy soils with sufficient soil moisture. Fescue withstands high soil moisture if the soil is deep and adequately aerated but it has low tolerance to prolonged flooding. Soil reaction may range from 4.5 to 7.0. Three species of fescue are grown in Canada; *F. rubra* L., red fescue; *F. pratensis* Hudson, meadow fescue; and *F. elatior* L., tall fescue. Tall fescue is probably the most widely adapted to different soil types, growing well both on highly acid and highly alkaline soils.

REFERENCES: 129, 130, 135, 157

LOLIUM PERENNE L. -- perennial ryegrass

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This short-lived perennial reacts like an annual under climatic conditions existing in the Maritimes, Quebec and Eastern Ontario. It is winter-hardy throughout the Prairie Provinces. It resumes growth at 1-2°C and is not tolerant of heat stress.

WATER: Ryegrass requires more water (75-125 cm annual rainfall) than any other Canadian agricultural grass to maintain optimum growth under a mild climate and on fertile soil. Hot, dry periods induce dormancy.

SOIL: The best production is achieved on fertile clays and loams with adequate moisture and good to excellent drainage. The species does not thrive on soils with slow drainage or which are susceptible to flooding. Soil pH should be maintained between 5.5-7.0. Poor growth occurs on thin sandy soils subject to drought.

REFERENCES: 120, 129, 130, 135, 144, 157

PHLEUM PRATENSE L. -- timothy

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This perennial is well suited to temperate climatic zones. It prefers a warm, humid climate, but does not tolerate hot temperatures. Timothy resumes growth at 2-3°C.

WATER: Production is limited by water shortages during the summer. Timothy requires at least 50 cm of rainfall annually; consequently it has limited use in Western Canada. It is very sensitive to water stress at flowering. Unlike brome-grass and orchard grass, it has a superficial root system which notably limits water uptake, and reduces production during hot, dry summers.

SOIL: Although timothy can grow on many soil types, maximum production is attained on well drained fertile loams and clay loams. Yields gradually decrease as drainage becomes poorer. Among the forage grasses, timothy gives the best yields on wet, cool heavy clay soils. There is low production on acid, infertile, sandy and thin soils. Soil pH should be between 5.5 and 8.0.

REFERENCES: 99, 130, 135, 144, 154, 157

POA spp. -- bluegrass; *P. PRATENSIS* L. -- Kentucky bluegrass; *P. COMPRESSA* L. - Canada bluegrass

LIGHT: The best growth is achieved under full sun conditions; in shaded areas, good growth may be attained given sufficient water and fertilizer.

TEMPERATURE: This perennial is grown in areas north of the 20°C annual isotherm and 27°C summer isotherm, where temperatures range from -25°C to 38°C. It resumes growth at 5°C; optimum air temperatures for growth range between 15°C and 28°C. Permanent damage is caused by temperatures above 35°C. Optimum soil temperature is 15°C at a depth of 5 cm. Bluegrass is winter hardy and well adapted to Canadian climates.

WATER: Good yields are achieved with annual rainfall of 60-125 cm. Bluegrass is one of the best pasture and forage grasses in North America where rainfall is above 60 cm. Rainfall is too low in the Prairies for successful production. Weak growth results during prolonged warm, dry periods, during which time the plants enter into a state of dormancy. Canada bluegrass is more drought resistant than Kentucky bluegrass.

SOIL: Bluegrass is successful on many types of soil (sandy to heavy clays with low fertility); the best growth is achieved on fertile, well drained soils with high organic matter. Soil pH of 5.5-8.0 should be maintained. Bluegrass can tolerate spring flooding for limited periods.

REFERENCES: 129, 130, 135, 150, 157

FORAGE CROPS - LEGUMES

ASTRAGALUS CICER L. -- cicer Milkvetch

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This cool season perennial resumes growth at 2-3°C. Winter hardiness of the crop has been established through variety trials in northern Alberta and the Yukon.

WATER: Milkvetch grows well on soils with both moderately high and low moisture contents. It does not tolerate flooding and is resistant to drought.

SOIL: Milkvetch is suited to the Black and Dark Brown soils. It is used as a soil stabilizer for road banks and to restore disturbed soils. It is tolerant of high salt contents.

REFERENCES: 107, 157

CORONILLA VARIA L. -- crownvetch

LIGHT: There is no limitation by photoperiod. Seed production is best under high light intensity.

TEMPERATURE: This perennial crop is suited to moderately cool temperate climates. The best growth is observed when temperatures are above 16°C; the plant becomes dormant at or below 10°C. Although young plants are susceptible to winter kill, once well established crownvetch will tolerate temperatures of at least - 35°C. Excellent growth is usually observed when air temperatures are 18°C - 24°C and soil temperatures 13°C - 20°C. Crownvetch starts to flower in June with blossoms peaking in 2-3 weeks. Occasional flowers can occur through the rest of the summer and there may be a second flush in early fall; flowering may occur on new vegetative growth during late August and early September. In the fall, cool night temperatures and overcast weather may delay seed maturation. Crownvetch seeds require 6-9 or even 10 weeks to mature after pollination, and maturation is greatly reduced by cool temperatures and low light intensity.

WATER: This plant requires a regular water supply to maintain adequate growth. However, it is more tolerant to drought than excess moisture. The seeds require high soil moisture for germination. When soil moisture is favorable, a flush of new vegetative growth can overtop the developing seed pods, which then either do not mature or mature very slowly. Low relative humidity intensifies the shattering of mature seeds.

SOILS: Crownvetch grows on a wide range of soil types, but it is most suited to fertile well drained, sandy loams, loams and clay loams. Once established, the species may tolerate some soil acidity and infertility. For good growth, pH should be 6.0 or above and potassium and phosphorus content should be moderately high. It does not grow well on poorly drained soils, but is quite tolerant to salts.

REFERENCES: 49, 157, 168

VICIA FABA L. -- broad bean

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This annual germinates slowly at cool (4-5°C) soil temperatures. Better germination and good growth are achieved at warm soil temperatures of 18-22°C. This crop requires 140 days for mature grain and 100 days for good forage production. Seedlings are resistant to late frost with no damage at temperatures as low as - 4.0°C. There is minimum growth below 5°C and above 25°C; optimum growth occurs between 15° and 20°C.

WATER: Broad bean is not drought tolerant and requires regular rainfall during the growing season. It is affected by water

stress particularly during flowering and pod formation. Dry conditions are desirable for maturation of pods. Broad bean can tolerate flooding for few days at early growth stages.

SOIL: This crop should be grown on clay loams and clays with high water holding capacity due to the high water requirement. Good surface drainage is also necessary. Early planting in warm, well drained soils is required. The best growth is achieved when soil pH is circumneutral (6.0 - 7.5) and fertility is high. Poor production results on light sandy soils due to low moisture content and to the warm, dry periods common at flowering time.

GENERAL: Broad bean is suited to areas of heavy soils with a moderately cool, humid climate. Early planting is desirable, because of the long growing season needed for pod production. In Eastern Canada, it is possible to let the crop mature on the stand before harvest, but in Western Canada, due to a drier climate, it is preferable to swath when 40% of the pods reach maturity to avoid pod drop at harvest.

REFERENCES: 28, 29, 33, 98, 108, 137, 157

LOTUS CORNICULATUS L. -- bird's foot trefoil

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This cool-season perennial resumes growth at 3-4°C. Varieties such as 'Empire' and 'Viking' are more winter hardy than alfalfa and clover. European varieties ('Dupuits', etc.) have low cold-tolerance.

WATER: Bird's foot is tolerant to drought, and is capable of achieving better production under dry conditions than white clover, ladino clover and red clover, but lower production than sweetclover and alfalfa.

SOIL: Good growth is achieved on heavy, fertile and well drained soils, but the plants tolerate many soil types. Drainage may vary from good to poor and pH from 5.5 to 7.5. Bird's foot is often suitable for pasture where soil conditions prevent the use of other crops.

REFERENCES: 96, 120, 129, 130, 134, 135, 154, 157

MEDICAGO SATIVA L. -- alfalfa, lucerne

LIGHT: Dry matter production and flowering are enhanced by a long photoperiod. Most alfalfa cultivars are long-day plants but response to photoperiod varies between cultivars. Often photoperiod interacts with temperature.

TEMPERATURE: Soil temperatures of at least 10°C promote high nitrogen fixation by the symbiotic bacteria present in the root nodules, thus promoting good growth. Temperatures for germination should be 10°C - 35°C with an optimum of 25°C; temperatures for foliage growth should be 8-10°C minimum, 15-30° optimum and 35-40°C maximum. Foliage is killed by temperatures below -3°C. Winter hardiness varies between cultivars. Cold hardening occurs at temperatures from 15° to -5°C (optimum: -5° to 8°C). Alfalfa is a mild to cool season perennial crop.

WATER: Alfalfa has high water requirements of 800 gram/gram of dry matter, or 6 - 8 mm of water per day during warm summer days. Although this plant can grow in areas with low precipitation, the best yields are obtained in regions with good rainfall distribution during the growing period. Generally, each 15 cm of water yields 2200 kg of dry matter per hectare. Alfalfa has an excellent deep-growing root system.

SOIL: Many soil types are suitable for alfalfa, providing there is good drainage, circumneutral soil reaction (pH 6.5 - 7.5) and a high fertility level. The best results are obtained on deep loams and clay loams, with porous subsoils.

GENERAL: *Medicago sativa* includes a siberian variant, *M. sativa* subsp. *falcata* (L.) Arcangeli (*M. falcata* L.), which is very much more cold-tolerant, and tolerant of somewhat acidic soils, than most forms of *M. sativa*. The cultivar 'Grimm' and similar cultivars contain much germ plasm from subspecies *falcata*, and are responsible in considerable part for the success of alfalfa in Canada. Cultivars are available which are adapted to specific climates (cold, mild, warm, humid, dry) and soils (clay to sand). Some cultivars can survive cold temperature as low as - 64°C and as hot as 49°C.

REFERENCES: 17, 75, 96, 120, 128, 129, 130, 131, 154, 157

MELILOTUS spp. -- sweet clover; *M. ALBA* Desr. — white sweet clover, *M. OFFICIANALIS* (L.) Pall. -- yellow sweet clover

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: The two species grown in Canada are cool-season, perennial, winter hardy crops; they resume growth at 2-3°C.

WATER: Sweetclover is drought resistant and suited to semi-arid areas. It requires at least 40 cm of rain during the growing season for a good yield and has an excellent, deep-growing root system.

SOIL: The best yields are obtained on fertile, near-neutral (pH 6.5-8.0) loams and clay loams. Good results are obtained on sandy loams, and clays, and on soils with low fertility such as Gray Luvisols. Good drainage is preferred but the crop succeeds better than alfalfa or red clover in poorly drained areas. It will not tolerate spring flooding for more than 10 days.

REFERENCES: 96, 129, 130, 135, 144, 145, 157

ONOBRYCHIS VICIIFOLIA Scop. -- sainfoin

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This perennial can be grown in Western Canada where alfalfa is successful, but it is generally less winter hardy than the latter.

WATER: Sainfoin has good resistance to drought due to an extensive, deep-growing root system. It requires at least 35 cm of annual rainfall.

SOIL: Sainfoin is suited to thin, light soils, and grows well on calcareous soils. It is not tolerant to salts, and does not grow on water logged soils. It is well suited to Black and Dark Brown soils in Western Canada, but low yields result on Gray Luvisol and Brown soils.

REFERENCES: 128, 152, 157

TRIFOLIUM spp. -- clover; *T. PRATENSE* L. -- red clover; *T. REPENS* L. -- white clover, ladino clover; *T. HYBRIDUM* L. -- alsike clover.

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: These perennial cool-season crops resume growth at 4-5°C and have limited winter hardiness.

WATER: Clovers, in general, require a good water supply for adequate yield. They cannot withstand drought due to their superficial root system. The best results with red clover are obtained where annual rainfall reaches 100-120 cm. Alsike clover is well suited to humid soils and can withstand high soil moisture levels.

SOIL: Better yields are achieved on loams and clay loams than on sandy soils. Alsike clover grows well on well drained clay soil. It can endure spring flooding for at least 5 weeks and can grow on soil too acid or too alkaline for other perennial legumes (pH 5.0 to 8.0). Red clover grows well on calcareous loams and clay loams which are well drained, but it will not survive on sandy soils. It requires a fertile soil of pH 5.5 - 7.5, and is more tolerant to acidity than sweetclover. White and ladino clovers prefer loam and well drained clay soils but grow

well on sandy soils if there is a high water table; they prefer a pH between 5.0 and 7.0.

GENERAL: Red clover is widely grown in Eastern Canada; it is well suited to conditions in British Columbia, to the Black and Gray Luvisol soil zones of Alberta, Saskatchewan and the inter-lake area in Manitoba. It is not recommended for lands with low rainfall. Alsike clover is useful in farming rotations because it improves soil structure and fertility levels in areas with high rainfall.

REFERENCES: 96, 129, 130, 134, 135, 143, 149, 154, 157

OILSEED CROPS

BRASSICA spp. -- rape; *B. RAPA* L. -- rape, turnip rape, Polish (type) rape; *B. NAPUS* L. -- rape, Swede rape, Argentine (type) rape.

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Rapeseed is a cool season crop, grown mostly as an annual in Canada. It prefers cool temperatures up to the flowering period, but is tolerant of high temperature during the reproductive phase. There is a net decrease in grain size and oil content under warm, dry conditions. Cool nights aid recovery from water and heat stress. Rapeseed can withstand light frosts but suffers serious damage under a severe frost. The growing season is 87 - 95 days for *Brassica rapa* and 104 - 109 days for *B. napus*. Winter (i.e. biennial) rapeseed has proven completely unsuccessful in the Prairies but could be grown in Eastern Canada if yields and market were favorable.

WATER: The daily evapotranspiration rate is about 7-8 mm during hot, dry days. Water stress during generative and reproductive phases adversely affects grain formation, grain size and oil content. This crop is less tolerant to drought than wheat.

SOIL: Rapeseed can be grown on different soil types. It grows well on sandy soils if water is not limiting. Yields are better on loam and clay loam soils in drier area because of higher moisture retention. This crop tolerates a wide range of soil pH, and it tolerates salinity in semi-arid climates.

REFERENCES: 10, 24, 48, 124, 151, 157

LINUM USITATISSIMUM L. -- flax

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Flax is a cool season annual crop which requires 105-115 days to reach maturity. A frost at 0°C will not affect a plant 12-15 cm high but will result in serious damage at flowering and milking stages. Young seedlings are tolerant of light frost (0° to -2°C) just following emergence; seedlings 6-9 cm high (3-5 leaves) can withstand severe frosts (-8° to -11°C) of short duration without damage.

WATER: Due to its superficial root system, flax is susceptible to dry, warm periods. It requires good rainfall distribution during the growing season, but cannot tolerate excessive moisture.

SOIL: Although this crop can be grown on many soil types with adequate moisture supply, the best yields are obtained on fertile, well drained loams and clay loams. Soil reaction should be between 5.5 and 7.0; imperfect drainage will result in lower yields.

REFERENCES: 99, 110, 119, 120, 133, 154, 157

SINAPIS ALBA L. -- white mustard; *BRASSICA JUNCEA* (L.) Czerniak -- brown mustard, oriental mustard.

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Mustard is a cool season crop suited to a short growing season, varying with varieties from 88 to 96 days.

WATER: Mustard is more tolerant of dry periods than rapeseed. It is usually grown in areas where rainfall is limiting for the latter. The best yields and quality are obtained in dry southern lands of Saskatchewan and Alberta.

SOIL: Mustard is adapted to the Brown and Dark Brown soils of the Prairies. It will tolerate alkaline and slightly saline soils.

GENERAL: Both *Sinapis alba* (white mustard) and *Brassica juncea* (brown mustard) are grown in Canada. The two have fairly comparable edaphic requirements.

REFERENCES: 124, 151, 157

HELIANTHUS ANUUS L. -- sunflower

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This is a mild to warm season crop, but it can succeed in cool areas if the soil warms early in the spring. Under conditions of the Canadian prairie, sunflowers must be planted early in May for harvest in October. Young seedlings are not damaged by temperatures as low as -10°C, but past the 6-8 leaf stage plants are susceptible to light frosts (0° to -2°C). This crop can be grown in areas beyond the climatic limits for soybean and corn because it is more resistant to low temperatures.

WATER: Sunflower requires a good supply or water because of its high evapotranspiration rate; a 50 mm deficit during the critical flowering and seed maturation stages causes decreased yields. It requires irrigation under dry climatic conditions; irrigation tends to increase oil content (3-5% more oil in the seed) but to lower protein content. Water stress and the action of a fungus (*Macrophomina phaseoli*) have deliterious effects on seed formation.

SOIL: The plants require fertile, deep and well drained soil. This encourages development of long roots and provides protection against water stress. Loams and clay loams give the best results; cool, poorly drained soil must be avoided. Sunflower can tolerate poor quality soils, but at the cost of considerably lower yields.

REFERENCES: 62, 63, 64, 147, 154, 157

CORN (SILAGE, GRAIN, OIL AND SWEET CORN)

ZEA MAYS L. -- corn, maize (silage, grain, oil, sweet corn)

LIGHT: Corn is one of the few crops in Canada using the C_4 photosynthetic system, and therefore is best suited to warm temperatures and high light intensity. Further promoting good productivity are its capacity for rapid growth and extension, early development of an optimum leaf area index and leaves remaining active up to grain maturation. Corn is one of the best crops for sunlight utilization and conversion to dry matter. It is insensitive to photoperiod.

TEMPERATURE: Corn requires a minimum soil temperature of 10°C for germination and root development; optimum soil temperatures for germination and seedling development are 18°C - 22°C. When planted at 7.5 cm below the soil surface, 68 degree-days above 10°C are required for emergence (in practise, about 10 days). Mean summer minimum temperature during the day and average minimum temperature at night should be about 16°C and 12°C respectively. To assure grain production in Canada, early hybrids require a minimum growing season of 130-140 days, an average minimum summer temperature of 18°C and a minimum of 2500 corn heat units (CHU). Corn can be grown for silage outside these limits but only in areas receiving at least 1900 - 2000 CHU. Late hybrids, which are generally high-yielding, require a growing season of 170-180 days, a frost-free period of 140-150 days, mean daytime temperatures of 24-28°C, mean night-time temperatures of 14-16°C and a CHU accumulation of 3100 or more. At flowering the minimum temperature should be at least 18°C; warm temperatures and dry conditions reduce pollinization efficiency. There must be at least 60 frost-free and warm days (22° - 25°C daytime) to attain grain maturation after flowering. Many new hybrids are fairly tolerant of late spring frost. After emergence, light frosts can damage young exposed leaves but, as long as the growing point is below the soil surface, new leaves are formed and the plant can recover.

Young plants can be seriously damaged or killed if the soil remains wet and cool after planting. For sweet corn production, duration of the frost-free period and the growing season varies with varieties, with a minimum of 80 days from planting to maturity.

WATER: High Production requires a good moisture supply. Corn needs at least 50 cm of rain during the growing season, and high evapotranspiration losses (20-30 cm during the growing season) can result in low yields. Corn is very sensitive to water stress at the flowering and fruit set stages.

Any excess of precipitation or irrigation waters above evapotranspiration losses improves the water efficiency ratio and results in a yield increase, providing that the potential evapotranspiration is balanced and the soil remains aerated. Rainfall is usually adequate for corn production in Eastern Canada.

SOIL: Corn production is possible on any deep soil with adequate fertility, good moisture retention properties and good aeration. pH should be maintained between 5.5 to 7.0 with an optimum near 6.5. Loams, clay loams and clays providing good drainage are excellent. Good surface and subsurface drainage are often necessary on heavy, imperfectly drained soils. The soil must warm early in the spring to allow early planting.

REFERENCES: 9, 24, 25, 26, 34, 89, 90, 91, 92, 120, 128, 153, 154, 157

SOYBEAN (GRAIN AND OIL)

GLYCINE MAX L. -- soybean

LIGHT: This plant attains maximum photosynthesis at relatively low light intensity: 2300 foot-candles at leaf level. Photoperiod is important; most varieties are sensitive to day length, and this becomes a limiting factor at high latitudes (49-55°N). Soybeans remain at the vegetative phase under long day conditions and flowering is rapidly initiated under short days. At northern latitudes day length is too long for most varieties, and flowering is inhibited or occurs so late that pod filling cannot be completed before the end of the growing season. Some early varieties developed for northern areas can begin flowering under continuous lighting.

TEMPERATURE: Soil temperature does not seem to influence germination success but it greatly modifies the germination process. Germination rate varies with soil temperature, the minimum is 5°C, optimum at 30° - 36°C, and germination is inhibited above 42°C. Some cultivars are suited to cool soil temperatures, with excellent germination rates at 18° - 20°C. Emergence and hypocotyl elongation are rapid when soil temperature ranges between 25°C and 35°C.

This annual crop is suited to warm, humid climates. Growth rate is minimal at 10°C, optimal at air temperatures 25° - 33°C and is inhibited at 37°C. Flowering is delayed by

approximately 2-3 days for each degree below 24°C. To reach maturity, early varieties require at least 2200 accumulated degrees-days above 5°C, a growing season greater than 180 days and a frost-free period of more than 140 days. Plants maintained at 29°C have 2-3 per cent more oil in the seed than those maintained at 22°C.

WATER: Available water is a limiting factor for soybean production. This plant can thrive under short dry periods but is sensitive to drought at germination and during early growth. Water shortages during pod formation are more critical than at flowering. Maximum yield reduction is observed when water stress conditions coincide with pod formation and pod filling. A minimum 35 cm of water is required during the growing season, and 70 cm evenly distributed during the late growing season is ideal for maximum yields. High soil moisture is desirable for good germination but excessive moisture is detrimental.

SOIL: Soybeans are suited to a range of soils providing there is good drainage, high fertility and adequate water holding capacity. Best results are obtained on fertile clays, clay loams and loams. This plant tolerates stagnant water for short periods, but this condition is not advisable. Near neutral pH conditions (6.0 - 6.9) are recommended.

GENERAL: An average of 55 - 60 days is required from emergence to flowering, for most varieties. Flowering continues into summer, allowing some plants to escape droughty periods, even if early flowers are lost due to water stress. Pod formation from late flowers is possible if water remains available.

REFERENCES: 15, 16, 30, 31, 54, 55, 56, 57, 58, 59, 60, 61, 154, 157

HORTICULTURAL CROPS - FRUITS

PRUNUS ARMENIACA L. -- apricot

LIGHT: There is no limitation by photoperiod, but high light intensity promotes fruit quality.

TEMPERATURE: Apricot, like all fruit trees grown in Canada, requires a winter dormant period for proper development and fruit production. It is limited to regions with 400-600 hours below 7°C to break the rest period. The root system is sensitive to cold soil temperatures during the dormant season, with exposure to -9°C causing severe damage. Fruit buds are severely injured at -25°C and killed at -33°C. Cold tolerance decreases as buds become active.

Among fruit trees grown in Canada the apricot requires the fewest hours of warm weather to open its flower buds, and consequently it blooms early and is especially susceptible to frost. Blossoms and young fruit are destroyed at -1.5°C. The apricot has adapted to areas with a long growing season and a mean summer temperature of 23° - 28°C.

WATER: This plant requires adequate available soil moisture throughout the growing season for best growth and production. A minimum 80 cm of water (rainfall and irrigation) should be available. It is particularly important to select soils that will retain large amounts of available water to carry the trees through periods of moisture deficiency

SOIL: This crop is suited to well drained, deep and fertile loams and sandy loams, with high water holding capacity. Soils should be maintained at a pH from 6.0 to 6.8.

GENERAL: This is not a common commercial crop in Canada but it is grown locally. It should be planted in protected areas to avoid cold and late spring frosts.

REFERENCES: 137, 157, 160, 163, 164, 165, 166

PRUNUS AVIUM L. -- sweet cherry; *P. CERASUS* L. -- sour cherry

LIGHT: There is no limitation by photoperiod, but the best production is achieved under high light intensity.

TEMPERATURE: This crop is suited to warm, temperate climates. Cherries require a winter dormant period for proper development and fruit production; 600-900 hours below 7°C is necessary to break the rest period fully. The trees require a long growing season and a frost-free period of 150 - 160 days. These trees are particularly sensitive to late spring frost. Minimum winter temperatures are critical, since buds are killed at -15°C. Winter hardiness and cold tolerance decrease rapidly as bud activity resumes; 50 per cent of the floral buds can be destroyed at -5°C or -6°C just before bud opening. There is minimum resistance at full bloom, and flowers are destroyed at -3°C. The critical temperature for fruit survival is -2.5°C. In orchards equipped for frost protection, temperatures should be maintained above -2°C when buds are at the "water stage" (40-50 mg fresh weight per bud).

WATER: This crop requires 300-500 mm of rainfall during the growing season, to give an average yield of 20-25 tonnes per hectare on sandy soils. Dry periods are required for flowering and fruit maturation.

SOIL: Cherries are suited to deep, fertile and well drained sandy loams and loams, with high organic matter and good water holding capacity. Soil pH should be maintained at 5.3 - 5.8; manganese deficiencies occur when pH is above 6.0.

GENERAL: The proximity of large water bodies helps prevent late frost in the spring and early frost in the fall.

REFERENCES: 79, 80, 81, 137, 153, 157, 160, 163, 164, 165, 166

PRUNUS DOMESTICA L. -- plum

LIGHT: There is no limitation by photoperiod; yield and quality are increased under high light intensity.

TEMPERATURE: This tree is suited to mild but cool temperate climates. Plums require a winter dormant period for proper development and fruit production and (European varieties) are limited to temperate regions with 600-900 hours below 7°C to break the rest period fully; cultivars derived from oriental varieties have a relatively shorter cold requirement period. During the dormant season the tender root system is damaged if soil temperatures drop below -7°C. Very frequently the tender collar or crown bark is killed at -1°C when sudden freezing follows periods of moderate temperature. Cold tolerance decreases as buds resume activity. Injuries are observed under the following conditions:

Phenophases	Little damage	Severe damage
Buds breaking, green tip stage	-2°C	-12°C
Buds open	-3.0°C	- 5°C
Buds fully open	-1.5°C	- 3°C
Petals shed	-1.5°C	- 2.5°C
Small green fruit	-1.5°C	- 2.5°C

Mature fruits are damaged at -2°C. The best production occurs when mean temperatures for June, July and August range between 18°C and 22°C.

WATER: The plum requires adequate available moisture in the root zone throughout the growing season. For best growth and production, a minimum of 60-80 cm of water (rainfall and/or irrigation) is necessary. In areas with prolonged periods of limited rainfall it is important to select soils that will retain a large amount of available water to carry the trees through periods of drought. Excessive soil moisture is detrimental to root systems.

SOIL: Deep, well drained soils with high fertility and high organic matter levels are required. European varieties are best suited to loams and clay laoms, oriental varieties to warm, sandy loams and American varieties to well drained clay loams and clays. Alkaline soils are not recommended because of iron and manganese deficiencies. Soil pH should be maintained at 6.0-6.5.

GENERAL: North slopes provide a delay in bud breaking in areas subject to late frost. Cold air temperature inversions should be considered in site selection. Soils that warm rapidly are preferred in areas where the climate is cool.

REFERENCES: 137, 140, 153, 157, 160, 163, 164, 166, 167

VACCINIUM spp. -- blueberry; *V. CORYMBOSUM* L. -- highbush blueberry, *V. ANGUSTIFOLIUM* Ait. -- lowbush blueberry

LIGHT: Blueberries prefer high light intensity, and yields are reduced under shaded conditions. Generally, flowering is initiated during the shorter days of spring, and flower bud formation is promoted during the shorter days of fall. Phenology becomes critical in northern latitudes, because flowering may be initiated while frost hazards still exist. Farther north, long days delay flower bud formation, in which case cold temperatures inhibit development.

TEMPERATURE: This is a perennial plant, propagating by rhizomes. At 21°C seeds will germinate within 20 to 30 days. It is a common practice to burn old wood of lowbush blueberries late in the spring to promote new plant development. New stems emerge after 350 - 400 degree-days accumulation (42°F) when soil temperatures are 12°C - 15°C. The best yields from lowbush blueberries are obtained when the average temperature during the growing season is 18°C; a higher average temperature is required for highbush blueberries. High temperatures of 35° - 38°C cause damage to both lowbush and highbush plants. Flower buds are killed by temperatures of -28°C to -40°C and snow cover is important for winter survival. Late frosts cause damage to flowers and fruits; a frost-free season of 100 days is required for blueberries under field conditions. Under short photoperiods and warm temperatures (8 hours and 25°C) there is more flowering than under short photoperiods and cool temperatures (8 hours and 16°C).

WATER: Blueberries require at least 4-5 cm of water every week during the growing season and irrigation is desirable during dry periods. The water table must be at least 30 - 40 cm beneath the surface to maintain adequate aeration.

SOIL: Blueberries are well suited to sands and sandy loams with low organic matter (4-5%). The soils must be well drained. A pH of 4.0 - 5.2 is ideal. Some varieties can grow in organic soils, but water table must be maintained below 30 - 40 cm.

REFERENCES: 22, 23, 85, 100, 103, 157

FRAGARIA x *ANANASSA* Duchesne -- strawberry

LIGHT: Response to photoperiod and light intensity varies with cultivars. Runner development is controlled by photoperiod interacting with temperature. A photoperiod of more than 12 hours and temperatures above 10°C are required for runner initiation; optimum conditions are a 15 hour photoperiod and temperatures of 22°C.

TEMPERATURE: This perennial is suited to cool, humid climates. Although it is not propagated commercially by seeds, it may be noted that the optimum temperatures for seed germination are 21° - 25°C. In the winter, severe damage may occur at -9°C, and plants are often killed at -23°C, depending on cultivar. The plant is sensitive to late frosts; flowers and other tissues are damaged at -1°C and very severe damage occurs at -3°C. Flowers and fruits of some cultivars are destroyed at -2°C. Irrigation to prevent frost should be started when temperatures in the vicinity of the plant reach 1.7°C.

WATER: Due to its superficial root system, strawberries require at least 2.5 cm of water a week on loams and 5.0 cm on sandy soils. Generally production is possible without irrigation in areas where rainfall is regular and reachs 70 - 90 cm per year. Excessive soil moisture is not desirable.

SOIL: Strawberries are suited to a wide range of soils, providing these are fertile and well drained, and have high organic matter levels and adequate water holding capacity. The best results are achieved on sandy loams and loams. Excessively sandy and poorly drained clay soils should be avoided. Sub-surface drainage is often essential to promote adequate root development. Optimal pH levels are 5.5 - 6.3, and the crop is not tolerant of alkaline conditions.

REFERENCES: 13, 14, 53, 94, 113, 118, 121, 153, 154, 157

RUBUS IDAEUS L. -- red raspberry, European raspberry, American raspberry

LIGHT: There is no limitation by photoperiod, and production is not reduced under slightly shaded conditions.

TEMPERATURE: This perennial is suited to cool, humid climates. Winter hardiness varies with cultivars, with some varieties surviving at temperatures as low as -35°C. The best yields are obtained when average temperatures during the growing season are 18° - 21°C. Fruit sensitivity to cold varies with cultivars: -0.9°C for red fruit cultivars and -1.8°C for black fruit cultivars (*R. occidentalis* L.).

WATER: Three to five cm of water per week are required. Excessive soil moisture can damage root systems and reduce yields.

SOIL: Raspberries are suited to deep sandy loams and loams with good drainage and high water holding capacity. Gravelly soils should be avoided due to low fertility levels and droughtiness. Heavy soils with poor drainage are not recommended. Soil pH should be maintained at 6.0 - 6.5.

GENERAL: Sites protected from wind are recommended.

REFERENCES: 107, 134, 153, 154, 157

RIBES spp. -- currant and gooseberry; *RUBUS* spp. -- blackberry, dewberry

LIGHT: There is no limitation by photoperiod, but production is better under high light intensity.

TEMPERATURE: These perennials are suited to cool, humid climates. Winter hardiness varies with cultivars; currants and gooseberries are generally more resistant to low winter temperatures than blackberries and dewberries, which can be destroyed by short exposures at -28°C to -34°C. Fruit tolerance to cold varies with cultivars; fruits are generally destroyed at -2°C.

WATER: The plants require 3-5 cm of water weekly during the growing season; excessive soil moisture damages root systems and reduces yields.

SOIL: The crops are suited to deep, fertile, sandy loams and loams, with high organic matter and good drainage. Heavy soils are acceptable if well drained, but yields are generally lower.

REFERENCES: 137, 153, 157

PYRUS COMMUNIS L. -- pear

LIGHT: There is no limitation by photoperiod; yield and quality are increased when grown under high light intensity.

TEMPERATURE: This tree is suited to mild but cool temperate climates. Varieties of pears of European origin require a winter dormant period for proper development and fruit production and therefore are limited to temperate regions with 600-900 hours below 7°C to break the natural rest period. Pears with germ plasm from the relatively cold-hardy Oriental pear (*Pyrus pyrifolia* (Burm. f.) Nakai) have a relatively shorter cold requirement (such pears, however, are not of commercial importance in Canada at present). During the dormant period, the tender root system is injured if soil temperatures go below -7°C. Sudden freezing following periods of moderate temperatures might injure collar or crown bark even if temperatures do not go below -1°C. Fruit buds are sensitive to winter temperatures below -12°C. Cold tolerance decreases as buds resume activity. The northern limit for pears coincides with the -34°C minimum winter temperature isotherm. Injuries occur under the following conditions:

Phenophase	Little damage	Severe damage
Buds breaking green tip stages	-3°C	-9°C
Buds fully open	-2.0°C	-3.5°C
Flowering	-1.5°C	-3.5°C
Fruit set	-1.0°C	-3.0°C
Small green fruit	-1.0°C	-2.8°C

Mature fruits are damaged at -2.0°C. The best production is achieved when mean temperatures for June, July and August are between 20°C and 25°C.

WATER: A minimum of 100 cm of water (rainfall and irrigation) should be available during the growing season for commercial culture. Soils that retain large amounts of available water are required to carry the trees through periods of drought; excessive soil moisture is detrimental to the root system. Pears suffer from the deadly bacterial disease "fire blight". This is brought on by high humidity such as occurs in much of eastern North America, and has restricted large-scale pear-growing in Canada to mild dry valleys of British Columbia, to narrow regions bordering the Great Lakes, and to protected river valleys on the Atlantic seabord.

SOIL: Pears require deep, well drained, fertile soils. Loams and sandy loams are the best, but pears are more tolerant than other fruit trees to clay soils providing that these are well drained. Slightly acid soils (pH 5.8 to 6.5) are recommended; copper deficiencies are common on alkaline soils.

REFERENCES: 91, 113, 137, 153, 157, 160, 163, 164, 165, 166, 167

MALUS PUMILA Mill. -- apple

LIGHT: There is no limitation by photoperiod; production is better under high light intensity.

TEMPERATURE: This perennial is suited to mild but cool temperate climates. A winter dormancy period of 900 - 1000 hours at temperatures below 7.2°C is required to obtain floral development. The northern limit coincides with the -37.5°C minimum winter temperature isotherm; trees are severely damaged and even killed under such conditions. Cold is a critical factor in Quebec, New Brunswick and Northern Ontario, where many apple trees were destroyed during the winters of 1904, 1917 and 1934. Frost tolerance decreases as buds resume activity; apple trees are sensitive to late spring frost. Critical thresholds are as follows:

	Little damage	Severe damage	Very severe damage
Green buds	-5.0°C	-7.0°C	---
Pink stage	-4.2°C	-6.0°C	-8.0°C
Flowering	-3.8°C	-5.1°C	-6.5°C
Fruit set	-2.7°C	-3.8°C	-5.0°C
Young fruit	-2.0°C	-2.5°C	-3.8°C

Mature fruits are also sensitive to frost, with damage occuring at -2.0°C. Warm temperatures in late summer and early fall delay fruit coloration, particularly in Southern Ontario. These conditions are critical also in cooler areas because new wood maturation is delayed permitting damage during the winter.

WATER: This crop requires at least 50-60 cm of water, regularly distributed throughout the growing season. Rainfall is adequate to assure normal production in Eastern Canada. Soil moisture should not drop below 40 per cent of field capacity during the growing season, to obtain high yields, especially in gravelly soils. Excessive soil moisture is undesirable for the root system.

SOIL: Apple trees are suited to deep, well drained soil with good water holding capacity. Ideal soils are deep sandy loams and gravelly loams. The soil layer available for root development should be at least 40 cm and preferably 140 cm deep, particularly in areas subject to dry periods during the growing season. Hardpans, claypans and dense subsoils retard root development and drainage, and should be avoided. Iron and manganese deficiencies are common in calcareous soils. Lower yields and frequent winter damage occur on trees growing on poorly drained soils. Slightly acid conditions are desirable (pH 6.0 - 6.5).

GENERAL: Good drainage and protection against late frosts are very important. Proximity of a large water body is desirable because it delays bud activity until late spring frosts are over, provides warm temperatures during summer and fall, and protects against early fall frosts. Trees should be planted where there is no problem with cold air inversions.

REFERENCES: 72, 73, 74, 91, 109, 113, 137, 141, 153, 157, 160, 163, 164, 165, 166, 167

VITIS spp. -- grape; *V. LABRUSCA* L. — fox grape, *V. VINIFERA* L. -- wine grape, European grape.

LIGHT: There is no limitation by photoperiod; yield and quality are increased under high light intensity.

TEMPERATURE: Commercial grape plants are suited to warm climates. Growth resumes in spring when temperatures reach 10°C. An average daily temperature of 16° - 19°C is necessary in May, June and July to assure high growth rates and fruit development. Higher temperatures of 19° - 23°C and sunny days are required in August, September and October to assure maximum yield and good fruit maturation. A minimum growing season of 170 days and a frost-free period of 150 days are required for early varieties. Based on 50°F, early varieties require at least 1800 degree-days to reach maturity; as much as 3500 degree-days might be necessary for late varieties. The growing

season and frost-free period must be long enough to allow fruits to reach maturity, and leave two extra weeks for harvest for commercial operations. It is desirable to have a rest period of 2 - 3 months where temperatures are below 10°C and above 1°C. Flowers are damaged at 0°C and fruits are destroyed at -2.2°C.

Table grapes and considerable wine grapes are produced from *Vitis labrusca*. Many available commercial wine varieties were developed from hybrids between American species and the European wine grape *Vitis vinifera*. The European or vinifera varieties (*Vitis vinifera*) which have been tested in Canada have rarely proven to be commercially satisfactory. Most of these require a longer, warmer summer and many are not winter hardy. French hybrids were developed by crossing European varieties (*Vitis vinifera*) with certain wild American species (*Vitis rupestris* Scheele, *V. lincecumii* Buckl. and others) to maintain fruit quality and gain winter hardiness. Characteristics differ between varieties in regard to climatic requirements and fruit quality. It is important for growers to establish market requirements and climatic possibilities before making a choice. It is often necessary to give special protection to plants to prevent winter killing.

WATER: Grapes require at least 15 cm of water from May to July and 12 cm from August to October when fruits are ripening. Excessive soil moisture is detrimental.

SOIL: For wine production, deep sandy loams and gravelly loams with high organic matter, good water holding capacity, moderate fertility levels and well drained subsoil are preferred. These soils warm early in spring and assure good root development. Loams and clay loams are also suited to grape production if well drained, but only for certain varieties.

GENERAL: The length of the growing season for some varieties is sometimes influenced by rootstocks, and often grafting given cultivars onto hardy rootstocks allow grapes to be raised in areas of relatively difficult climates.

REFERENCES: 86, 87, 88, 91, 113, 114, 115, 153, 157, 160, 161, 163, 164, 165, 166

HORTICULTURAL CROPS-VEGETABLES

ASPARAGUS OFFICINALIS L. -- asparagus

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Germination is slow and very irregular at soil temperatures of 15° - 18°C. At higher soil temperatures (27° - 30°C), germination is good and regular. Germination is inhibited when soil temperature is too high (40°C).

This perennial plant has an average life of 15 years once well established. Air temperature must reach 5.5°C to maintain growth. Early in the season young stems require 120 degree-days (42°F) to reach 20 cm, and later 410 degree-days to reach 150 cm. This plant needs a long dormant period and is well adapted to long cold winters or very dry summers. Slow growth in the spring to avoid late frosts is desirable. The time required for asparagus shoots to grow from 10 - 25 cm varies with mean daily temperature as:

11°C	-	5.3 days
14°C	-	4.2 days
17°C	-	3.4 days
19°C	-	2.4 days
22°C	-	2.1 days
25°C	-	1.9 day.

Low temperatures during the growing and harvesting season retard growth of the spears, and impair their edible quality (an accumulation of pigment results). At temperatures of 33°C and above lateral branches develop early.

WATER: Asparagus requires a good water supply but does not tolerate water logging.

SOIL: This plant can be grown on many soil types provided that they are deep and friable. The best results are obtained on deep sand or sandy loams with good moisture supplies. Gravelly soils and clays must be avoided because they bruise young stems as they grow through the soil. Soil must be well drained, and wet lands with an impermeable subsoil should be avoided.

Good production is obtained on soil with moderate organic matter content and a pH of 6.0 - 6.9; slightly alkaline soils are acceptable. Asparagus requires fertilization for good growth.

GENERAL: The plants should be protected from wind.

REFERENCES: 101, 121, 122, 148, 154, 157

DAUCUS CAROTA L. -- carrot

LIGHT: Most varieties are insensitive to photoperiod during the first year of growth.

TEMPERATURE: This is a cool climate crop that is grown as an annual for vegetables and a biennial for seed production. Soil temperatures of 25-26°C reduce germination and seedling development. Ideal soil temperatures for germination and root development are 15° - 20°C. Minimum temperatures for germination are 9°-10°C and at least 10 days are required when the soil is at 15°C. Air temperatures of 18° - 23°C are optimal; growth rate is low at 15°C and carotene content is reduced if temperatures are too high. Root development is reduced if soil temperature get too warm. Growing season varies from 85 to 150 days depending on planting dates and varieties. Yield and quality decrease if temperatures are high at the end of the growing season. Foliage, but not roots, is affected by light frost (-1.5°C).

WATER: This crop requires an adequate, regular water supply for good yields. Growth rate is reduced in dry soils and quality is affected in wet soils.

SOIL: This crop grows on many soil types but yield and quality will vary. Carrots prefer deep, friable, light, well drained soils; sandy loams and deep organic soils are ideal. Stony soils result in irregular root development and poor crop quality. Heavy and compact soils reduce root development and affect quality and nutritive value, and the crop is more susceptible to disease.

Light, well drained sandy and loamy soils promote excellent root development and permit early planting (since the soil warms early). Soil must be fertile with good organic matter levels and adequate water supply. A pH of 6.0 - 7.0 in mineral soils and 5.0 - 6.0 in organic soils is adequate.

REFERENCES: 11, 12, 91, 121, 122, 153, 154, 157

APIUM GRAVEOLENS L. -- celery

LIGHT: Celery is insensitive to photoperiod during the first year of development; high light intensity promotes good growth.

TEMPERATURE: Originating from maritime areas, celery prefers cool, humid climates with a long growing period and late, long, fall seasons. It is a biennial plant used as an annual for agriculture. The germination rate is optimum at soil temperatures of 16°C - 20°C. The best growth is observed when soil and air temperatures are 12°-16°C.

Flowering is initiated if seedlings are exposed to temperatures of 2-4°C for 10-15 hours; even at temperatures of 5°-10°C for 10 days, seedstalk formation occurs instead of vegetative development. Older plants may go to seed quickly and completely when chilled.

WATER: Celery, native to marshy habitats, requires high soil moisture and a regular water supply.

SOIL: A deep, well drained soil with high organic matter is required. Well drained organic soils are preferred but loams and sandy loams with a high organic matter are adequate, providing there is sufficient water supply. High fertility levels and a pH of 5.5 - 6.5 should be maintained to achieve good production. Clay soils should be avoided.

REFERENCES: 91, 121, 122, 123, 137, 138, 154, 157

ALLIUM CEPA L. -- onion

LIGHT: Onions are sensitive to photoperiod. Long days ensure leaf development and formation early in the growing period (bulb size is directly related to the number and thickness of the leaves). The plants need exposure to long photoperiods before mid-summer for leaf formation. Leaf formation ceases as reserves accumulate in the bulb. Depending on cultivar the process of bulb initiation begins when plants have reached adequate development and the photoperiod is 13-16 hours.

TEMPERATURE: This cool climate crop is frequently grown as an annual under Canadian conditions. Minimum germination occurs at soil temperatures of 6°-7°C; growth is slow when the soil is cool and wet. Bulb length is affected by soil temperature, with long bulbs formed at high temperatures. Temperature has little effect on bulb diameter and formation of lateral bulbs. Cool temperatures before bulb initiation yield strong plants but higher temperatures are required after bulb initiation for reserve accumulation. Bulb maturity is reached earlier when soil temperatures are 27-29°C, but yield is better when soil temperatures are 18°-24°C. High air temperatures of 20°-25°C are desirable at the end of the growing period and at harvest time. Onion seedlings tolerate a wide range of climatic variations; for most varieties, no damage occurs at temperatures as cold as -1.0°C. The length of the growing period is 95-120 days depending on cultivar. High temperatures and long photoperiods are essential to promote initiation and development for many cultivated varieties. Bulb initiation occurs even under short periods at temperatures of 16°-20°C.

WATER: The superficial, small root systems necessitate an adequate, regular water supply. Best yields are observed when moisture is maintained near field capacity. A dry period is critical immediately before bulb initiation and during the first phase of bulb formation. A small amount of rain promotes good drying, adequate bulb maturity and good quality at harvest, but rainy conditions might induce root formation and reduce quality.

SOIL: Onions can be grown on soils ranging from sand to clay. Sandy loams and loams with high organic matter levels, good drainage and good water holding capacity are suitable. Good yields are obtained on organic soils but mineral soils are preferable. Onions require high fertility levels and a pH of 6.0 - 6.7. Clay soils are not desirable.

GENERAL: Winds can cause severe damage at the seedling stage due to drying and erosion on organic soils.

REFERENCES: 5, 36, 37, 38, 39, 116, 121, 123, 153, 154, 157, 162

BRASSICA OLERACEA L. var. *CAPITATA* L. -- cabbage

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Good growth is achieved under cool, humid climatic conditions. Length of the growing season varies from 65 -125 days with varieties. This is a biennial for seed production but an annual for head production. Seed production is induced in the second year after plants are exposed to cold temperatures during fall and winter. Flower development and seed production are controlled by temperature:

Cold treatment	Temperature	Response
4 weeks	6°C - 7°C	Flowering
5 weeks	9°C - 10°C	Flowering
14 weeks	20°C - 23°C	No flowering

Longer cold treatments at a given temperature shorten the flowering period, for example 8-9 weeks at 6°C gives earlier flower formation than 4-5 weeks at 6°C.

Cabbage is cold resistant. Hardened seedlings tolerate -10°C to -12°C for short periods; young hardened plants are more cold resistant than older ones. Growth is minimal at 0°C, optimal at 15° - 20°C and stops above 25°C. Cabbage is not particularly hardy and will be damaged by sudden freezing when growing actively. Late varieties can still grow at 5°C during the fall; winter varieties are severely damaged by temperatures below -10°C to-12°C. For good yields under cool temperate climates, plants are started in greenhouses in early spring and transplanted to the fields in May or June.

WATER: Cabbage needs an adequate, regular water supply; 87-100 cm are required during the growing season. Adequate water is critical for head development.

SOIL: This plant can grow on many soils which are well drained and fertile, and have good water-holding capacity and adequate organic matter. Sandy soils are ideal for early varieties but clay loams produce better yields with late varieties. Organic soils are also used. This crop requires a high fertility level with near neutral pH (6.0 - 6.8).

REFERENCES: 91, 121, 122, 132, 154, 157

BRASSICA OLERACEA L. var. *BOTRYTIS* L. -- cauliflower

LIGHT: Effect of photoperiod on crop development is not well established.

TEMPERATURE: This annual crop prefers cool, humid climates; it is somewhat more tolerant of temperature extremes than cabbage. High temperatures during the growing season delay maturity, whereas cool temperatures hasten maturity. During the vegetative phase, growth rate is minimal at 0°C, optimal at 15°C - 22°C and stops at 30°C. Young hardened plants tolerate -5°C to -10°C for short periods. Head formation is affected by temperature and size of the plant. For early and summer varieties, the optimum temperature is 17°C; if temperatures remain above 20°C, head initiation and maturity are delayed. For late and winter varieties, head initiation occurs only when temperature is 10°C or less; head formation may not take place if planting is not carried out early in the season.

WATER: Cauliflower requires an adequate, regular water supply; dry conditions are critical at the reproductive phase.

SOIL: Under adequate climatic conditions, cauliflower can grow on many soils. It requires a deep, well drained soil, and high fertility and organic matter levels. Early varieties perform best on light soils if water supply is adequate. Summer and late varieties prefer loams and clay loams. Soil pH should be 5.7 - 6.5.

REFERENCES: 121, 122, 132, 137, 154, 157

CUCUMIS SATIVUS L. -- cucumber

LIGHT: There is no limitation by photoperiod. Best yields are achieved under high light intensity.

TEMPERATURE: This annual crop has a growing season of 60-85 days, varying with varieties. It is very sensitive to cool temperatures and might be killed at 1°C. Soil temperature at planting should be 10°C for table varieties and 13°C for gherkin varieties. Per cent germination and seedling vigor increase with temperature between 13°C - 30°C. Planting should be delayed until the mean temperature has reached 15°-18°C; a general rule is to defer planting until the average frost-free date of the locality has been reached. Plants should be protected against cold and wind. Optimum daytime temperatures for fruit formation are 25°-30°C and 18°-22°C at night.

WATER: Cucumbers are very susceptible to water shortage, due to their superficial root system; the crop requires a regular water supply.

SOIL: Deep, well drained soils with high organic matter, high fertility and good water holding capacity are required. Organic soils and compact clay soils are not recommended. Sandy loams are ideal for early varieties; loams and clay loams are recommended for high yields with late varieties. A pH of 5.5 - 6.7 is required.

GENERAL: Wind breaks are recommended to reduce leaf drying and disease dispersion.

REFERENCES: 50, 91, 121, 122, 154, 157

SPINACIA OLERACEA L. -- spinach

LIGHT: There is an interaction between photoperiod and temperature which induces flowering and seed formation. High light intensity improves dry matter yield.

TEMPERATURE: This annual crop prefers cool climates. Germination occurs within 7 - 10 days at 2°C. Only 50 - 60 days are necessary to reach plant maturity; under favorable conditions, 8-10 weeks are sufficient from planting to harvest. Spinach is cold-resistant with no damage observed at temperatures between -5°C and -7°C. Maximum growth is observed at temperatures of 10°C - 15°C. Under Canadian conditions, spinach can be grown at the beginning and the end of summer; warm mid-summer temperatures are inappropriate for most varieties. Spinach should be planted as soon as the soil is ready in spring and 30-35 days before occurrence of the first frost in fall. Early flower initiation and seed formation can occur in the spring when seedling are exposed to cold temperatures for 2-3 days followed by a gradual rise in temperature with longer days. This will not occur in the fall.

WATER: This plant requires an adequate, regular water supply; spinach is affected by water shortage, as well as excessive soil moisture.

SOIL: Well drained, fertile, sandy loams and loams with high organic matter are ideal; mineral soils are better than organic soils because they remain cooler during the day. Clay soils are acceptable if well drained. A pH of 5.8 - 6.8 is required.

GENERAL: Spinach is one of the few crops with male and female flowers on separate plants. Young male plants may begin seedstalk formation when exposed to cool temperatures and then to long daylength and rising temperatures. This problem is gradually being overcome by increasing the percentage of female plants in new varieties.

REFERENCES: 83, 91, 121, 122, 123, 148, 154, 157

PHASEOLUS VULGARIS L. -- snap bean, common bean

LIGHT: There is no limitation by photoperiod. Generally growth is enhanced by high light intensity.

TEMPERATURE: Soil temperature is important for germination; this is slow at temperature of 10°C-15°C and optimal at 21°-25°C. Soil temperatures of 13°-15°C at 10-15 cm depth are ideal for planting. This annual is not frost tolerant and plants are killed at -1°C to -2°C. Planting should be delayed until the mean temperature has reached 15°-18°C (A general rule is to defer planting until the average frost-free date of the locality).

This plant is suited to warm climates; growth rate is minimal at 9°-10°C, optimal at 28°-32°C and inhibited at 46°C. Optimum mean summer temperatures for growth are 18°-21°C. Since snap beans for market are harvested long before the seeds or pods are ripe, production is possible in areas having short warm summers with a minimum frost-free period of 100 days. A longer frost-free period is required for commercial production. Early varieties can be harvested in 8-10 weeks. Heat requirements increase for dry bean production and areas suitable for snap beans may be unsuited to dry bean production. Most dry bean varieties grown in Canada reach maturity 100-120 days after planting. Degree-days required to reach maturity vary from 900 to 1600 depending on varieties.

WATER: Beans require a regular water supply during the growing season, to maintain yield through several successive pickings. Water requirements are high during flowering and early pod development.

Germination is good when the soil is near field capacity. Yield and quality are affected more by excessive rainfall than by short dry periods. Dry conditions after pod filling are needed for adequate maturation of dry beans and dry sunny conditions are desirable at harvest time for production of snap beans.

SOIL: Beans are suited to a wide range of soils, provided that they are well drained and fertile, and have adequate water holding capacity and organic matter levels. Sandy loams are recommended for early harvests, but, better yields are obtained on loams and clay loams. Production on sandy soils is possible if fertility and moisture are adequate. Germination is poor and production is reduced on cool, clay soils. Soil pH values of 5.8 - 7.0 are ideal and production is reduced when pH is below 5.0. Calcareous soils are not recommended. Vegetative growth is excessive and yield is low on high organic matter soils.

REFERENCES: 76, 77, 97, 121, 122, 123, 128, 135, 157, 159

LACTUCA SATIVA L. -- lettuce

LIGHT: There is no limitation by photoperiod. Lettuce requires high light intensity for good growth.

TEMPERATURE: Lettuce is a cool climate, annual crop. The seeds germinate at 5^{o}-6^{o}C, but optimum germination temperatures are 14^{o}-20^{o}C depending on the cultivar. Germination is inhibited at temperatures of 25^{o}-28^{o}C. Growing season is 70-150 days, depending on the cultivar. Growth is promoted by temperatures of 13^{o}-15^{o}C, and leaf and head development is promoted by night temperatures of 10^{o}-12^{o}C. Hardened seedlings are cold tolerant (-5^{o} to -7^{o}C) but mature plants are sensitive to frost (-1^{o}C). Warm, dry conditions promote flowering and seed formation.

WATER: This plant requires an adequate, regular water supply to maintain good growth; it does not tolerate excess water.

SOIL: Lettuce can grow on many soils provided that they are fertile and well drained, and have high organic matter levels and adequate water holding capacity. Sandy loams are preferred for early production. For summer and fall production, excellent results can be obtained on organic soils. Lettuce has a high nitrogen requirement during early growth. The soil must be maintained at a pH of 6.0 - 6.8; manganese deficiencies will develop when soil reaction is alkaline.

REFERENCES: 69, 91, 122, 137, 154, 157

PASTINACA SATIVA L. -- parsnip

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: This annual is suited to cool climates. Germination and seedling emergence are optimal at 5-8°C. Suitable temperatures for growth are 13°-16°C. The plants are sensitive to frost at 0°C. The growing season of 80-150 days varies between cultivars.

WATER: Parsnips require a regular water supply to maintain good growth; dry periods reduce yield. The parsnip does not tolerate excess moisture.

SOIL: Performance is good on deep, well drained soil with good fertility. Sandy loams, loams and organic soils are adequate; pH should be maintainted between 5.8 and 6.5. The plant has a long root system whose development is restricted in shallow or clay soils.

REFERENCES: 121, 122, 154, 157

PISUM SATIVUM L. -- garden pea

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Soil temperature controls the germination rate, which is minimal at 4°-6°C, optimal at 16°-18°C and inhibited at 35°C. Planting should be carried out when soil temperatures at 10 cm are about 10°C for field production. This annual is suited to cool, humid climates; the best yields occur when temperatures are 15°-18°C. High temperatures at flowering cause yield reduction. Quality and high yield are achieved by early planting, which allows maturation before high summer temperatures occur. Degree-day accumulation from planting to maturity varies with cultivars from 1200 to 1800 (5.5°C). Peas tolerate cold temperatures of 0.5°-2°C without damage and some varieties are not affected at -2°C to -3°C.

WATER: This crop requires an adequate, regular water supply during the growing season. Adequate soil moisture is important for germination. The best yields occur when rainfall for May, June and July is frequent and totals about 30 cm. Studies in the U.S. have shown that a close correlation exists between yield and rainfall, with irrigation necessary during dry summers. This plant does not tolerate excessive soil moisture.

SOIL: Peas grow well on well drained soils with good water holding capacity, high organic matter and adequate fertility. Loams and clay loams are very suitable, and sandy loams are adequate for early production. Heavy clay soils with drainage and aeration deficiences can reduce

germination and plant vigor. High levels of nitrogen in organic soils enhance vegetative growth but reduce yield. Soil pH of 6.0-6.8 is required. Chlorosis occurs on alkaline soils.

REFERENCES: 35, 78, 95, 121, 122, 123, 135, 154, 157, 159

BRASSICA NAPUS L. var.*NAPOBRASSICA* (L.) Reichenb. -- rutabaga

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Turnips are an annual crop under Canadian conditions and are suited to cool, humid climates. Germination rate and seedling development are reduced at 5°-6°C, optimal at 15°-18°C and inhibited at 35°C. Turnips do not tolerate high temperatures. The growing season from planting to maturity is about 115 days for table varieties and about 130 days for animal feed varieties. This crop tolerates slightly cold temperatures, and foliage is not affected at -1.0°C.

WATER: This crop requires an adequate, regular water supply, and tolerates dry periods if soil moisture is available. The growth rate is strongly reduced by excess water.

SOIL: Turnips grow well on fertile, well drained soils with good organic matter and water holding capacity. Production is possible on sandy soils if moisture is available, but loams and clay loams are more suitable. Sandy loams are acceptable if fertility levels are adjusted. Organic soils may also be used. Soil pH should be maintained between 5.8 and 6.7 to avoid nutrient problems.

REFERENCES: 35, 105, 121, 153, 154, 157

LYCOPERSICUM LYCOPERSICON (L.) Karst. ex Farw. -- tomato

LIGHT: There is no limitation by photoperiod. Enhanced dry matter and fruit production occurs under high light intensity.

TEMPERATURE: This annual is suited to warm climates. Germination rate changes with soil temperature: minimum at 10°-12°C, optimum at 17°-20°C and inhibited at 35°-37°C. Emergence occurs after 25 - 30 days at 10°C, and after 4 - 5 days at 29°C. Seedling development is fast when soil temperatures are 23°-30°C, reduced at 33°C and inhibited at 35°-37°C.

Average temperatures must be at least 20°C during the growing season for commercial production. Growth rate is excellent at 22°C, and reduced at 30-35°C and 10°-12°C. The ideal regime is 22°-25°C during the day and 16°-20°C

at night. Day and night temperatures are critical at fruit set; fruit initiation and development is very good when day temperatures are 20°-25°C and night temperatures are 15°-20°C. Fruit set does not occur when night temperatures are less than 11°C or more than 20°C, nor when day temperatures are more than 32°C. A minimum of 2700 degree-days (6°C) is required for direct field planting. Under such conditions, the frost-free season must be at least 150 days. First fruits are formed 105-120 days after planting. This plant is not cold resistant and is destroyed at -1°C. Plants are started in greenhouses in early spring and transplanted outside when the danger of late frost is over.

WATER: Tomatoes require a regular water supply but soil moisture must be below field capacity. It is important to have adequate moisture at flowering and fruit set.

SOIL: Tomato plants can grow on soils varying from sand to clay, providing that the soils are fertile, well drained, and have good organic matter levels. Sands and sandy loams warm in early spring, which is ideal for early production and direct planting. Loams and clay loams are preferable for industrial production. Optimum soil pH is 5.8-6.5.

REFERENCES: 32, 70, 91, 102, 121, 122, 154, 157

CEREALS

AVENA SATIVA L. — oats

LIGHT: There is no limitation by photoperiod. The crop tolerates reduced light intensity better than many other small grains.

TEMPERATURE: This annual crop is suited to cool, humid climates. Germination rate varies with soil temperatures: minimal at 0°-5°C, optimal at 25°-31°C and inhibited above 31°C. Growing season length is 80 - 120 days, varying with cultivar. This crop is grown at latitudes up to the 16°C May isotherm and the 21°C July isotherm.

Winter oats are not grown in Canada, but they can be grown south of the -1°C isotherm (December to February). Growth rate is minimal at 3°-6°C and optimal at 12°-20°C. Warm, dry conditions are detrimental from early heading to grain maturity. Oat seedlings have good cold tolerance, but heavy frost in late summer or early fall before the crop has matured kills the plants, resulting in immature grain.

WATER: This crop requires a regular water supply with a minimum of 20-30 cm of rainfall from May to August. Oats are susceptible to drought

from early heading to grain maturity. Diseases are common in areas with more than 60 cm of rain. Although oats require more water than other small grains, excess soil moisture reduces growth.

SOIL: This crop is suited to a wide range of soils. It is tolerant of medium fertility and imperfect drainage. Good surface drainage is essential for early planting on clay soils. Oats grow on sand, sandy loams, loams, clay loams and clays. Minimum soil pH is 4.5, optimum is 5.5 - 6.5 and maximum is 7.5. The best yields occur on well drained, fertile soils with adequate water holding capacity.

REFERENCES: 6, 65, 91, 128, 134, 135, 154, 157

TRITICUM AESTIVUM L. -- wheat

LIGHT: This crop is sensitive to photoperiod. Wheat is a long day plant but the optimum photoperiod varies among cultivars. Light influence is modified by temperature. Spring-sown wheat varieties flower with more than 8 hours of daylight whereas short days maintain vegetative growth. Good light intensity is essential.

TEMPERATURE: Soil temperatures influence germination rate. Activity is minimal at 0°-5°C, optimal at 20°-28°C and inhibited above 32°C. Root development is optimal at soil temperature of 12°-18°C. The number of spikes and spikelets developed per plant is also influenced by soil temperature (optimal is 13-18°C) and varies among cultivars. A decrease of 1°C below optimum temperature reduces reproductive development.

Wheat is a cool season crop with a longer growing period and a higher minimum heat requirement than other small grains. The growing season for most varieties and cultivars is 100-120 days. Under frost-free periods of less than 100 days production is limited to areas where average summer temperature is above 11°C, with a minimum 1900 - 2000 degree-days (32°F).

Spring-sown wheat can be insensitive, semi-sensitive or sensitive to photoperiod. Insensitive cultivars respond to soil and air temperature, and flower only when a threshold of degree-days is reached. Consequently cool spring temperatures can promote vegetative growth and delay flowering, preventing maturation in short growing-season areas. Semi-sensitive types are ideal in Canadian conditions; vegetative growth is promoted by cool spring conditions, tillering is good and flowering is initiated when the photoperiod is adequate. There is good balance between vegetative and reproductive growth, and yield is better even in short growing-season areas.

With sensitive cultivars, the duration of the vegetative growth stage is more dependant on photoperiod than temperature; vegetative growth ceases and flowering is initiated as soon as photoperiod is adequate. Yield of late plantings is reduced in early summer under such conditions.

Warm temperatures during early growth may retard heading. Daily maximum temperatures above 32°C 3-4 weeks after flowering may cause premature ripening and yield reduction. The growth rate is minimal at 3°-5°C, optimal at 25°-30°C and inhibited above 40°C.

Extensive production is limited to areas with frost-free periods of more than 100 days; where this period is less than 90 days, production is precarious and possible only by early spring seeding and the use of short-season varieties. Wheat is seldom grown in areas with a subpolar climate where there are less than 3 months with average temperatures above 10°C. Early spring frosts are not destructive to spring-seeded small grains, which can recover quickly. Low temperatures prior to harvest result in slow grain ripening and possible damage from early frosts. The optimum average preharvest temperatures for wheat are approximately 14°-16°C.

Hardened winter wheat can tolerate -40°C when snow protection is adequate and -31°C without snow cover. Non-hardened winter wheat is severely damaged when exposed to temperatures of -5° to -10°C for long periods. Winter wheat may come into head before the danger of late spring frosts has passed; even a light frost of -1° to -2°C may kill pollen and partly or completely prevent fertilization of the flowers.

WATER: Wheat can be grown in areas where annual precipitation is 30 - 170 cm, but optimum is 70 - 85 cm, with 10 - 15 cm during the two months before harvest. Annual precipitation less than 50 cm together with a preharvest rain of less than 5 - 8 cm produces poor yields. Yield and quality are reduced under cool, rainy climates, and diseases are more prevalent. Adequate water supplies are critical during the period from shooting to shortly after heading. Excess soil moisture is detrimental.

SOIL: Wheat is suited to deep, fertile, well drained soils with good organic matter levels and without excess nitrogen. It can be grown on a wide range of soils but better yields occur on Chernozemic soil of loam and clay loam texture. Yield is better on clay loams than on sand and sandy loams. Near-neutral soils of pH 6.0 - 7.0 with an optimum of 6.5 are recommended. Winter wheat requires adequate surface and internal drainage. Surface drainage is essential for early spring seeding.

GENERAL: Winter wheat sown in spring may not produce grain unless the seeds or seedlings are exposed to cool or cold temperatures; seeding in very early spring is often required.

REFERENCES: 1, 2, 3, 65, 84, 91, 127, 128, 154, 155, 157

HORDEUM VULGARE L. -- barley

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Soil temperature influences germination rate: minimal at 2° - 5°C, optimal at 15° - 22°C according to varieties, and inhibition of germination above 35°C. Spring barley grows farther north and at higher elevations than other small grains. Early spring varieties require a minimum 80-90 days from seeding to maturity, but production is precarious in areas where the frost-free period is less than 90 days. Under adequate conditions 5-7 days are required from seeding to emergence and 10 - 15 days from emergence to tillering. Young plants can tolerate temperatures as low as -8°C.

This annual is suited to areas with approximately 2100 - 3000 accumulated degree-days (42°F), depending on varieties. Growth is minimum at 5°C and optimum at 10°-16°C during the vegetative phase. Minimum and optimum temperatures during the shooting to soft dough stages are 18°C and 24°-28°C respectively. Reproductive development is inhibited above 37°C. Low temperatures preceding harvest result in slow grain ripening and increase the risk of frost damage. Barley grows particularly well where the ripening season is long and cool.

The northern limit for winter barley coincides approximately with the -4°C isotherm for mean winter temperature (December, January and February). Winter barley is less hardy than winter wheat and winter rye.

WATER: Barley requires a minimum 30 - 50 cm annual rainfall under Canadian conditions, and about 85 cm in warmer climates. Growth is poor in warm, humid climates. Better growth is achieved with limited but regular rainfall. Excessive water reduces the growth rate. Development is faster in areas where precipitation is low, thus lowering the number of degree-days required to reach maturity. Adequate water supplies are critical during the period from shooting to shortly after heading.

SOIL: Barley is suited to deep, fertile, well drained loam and clay loam soils. Cold, acid, clayey and sandy soils as well as organic soils are not recommended. Surface and subsurface drainage are required for early seeding and vigorous growth. Optimal pH varies from 6.0 to 7.5.

REFERENCES: 4, 65, 66, 67, 91, 127, 128, 135, 154, 157

SECALE CEREALE L. -- rye

LIGHT: Generally the crop is insensitive to photoperiod, but some varieties adapted to northern latitudes, require a long photoperiod (14 hours or more) and a cool temperature (5° to 10°C) for flowering. Rye requires less sunshine than other cereals.

TEMPERATURE: Rye is grown in cool climates. Germination and emergence are influenced by soil temperature: minimum of 1° - 3°C and optimum of 13° - 18°C. Above 29°C, germination is inhibited for northern varieties.

Spring sown rye requires 60 - 90 days from seeding to maturity depending on the variety. This crop requires fewer degree-days and a shorter growing season than wheat or barley to reach maturity. Cloudy, cool conditions do not affect rates as much as for other small grains.

Spring rye requires temperatures of 5°-10°C for 8 - 10 days from the reproductive to the vegetative phase, followed by longer days. Tillering is weak at 3°-5°C and very good at 16°C. Grain maturation is excellent at 15°-20°C; the crop ripens prematurely at higher temperatures. A frost-free period of more 80 days is required.

Rye is more important as a winter than a summer cereal. Seeding in late summer and early fall is best when average temperatures are 10°-13°C. Growth ceases during the fall when temperatures reach 4°-5°C and resumes in the spring at the same temperature. Tillering in fall and spring is better at 12°-14°C. Good winter hardiness is ensured when the plants are exposed for 6-8 days to sunny conditions with cool temperatures of 5°-10°C and cold night temperatures from 0° to -3°C, followed by 20 - 30 days at -1° to -4°C.

Winter rye is the most hardy cereal crop and can survive temperatures lower than wheat. Winter hardy varieties can be sown in the fall with assurance of a good crop even in regions where the mean winter temperature is -18°C. Rye has survived -32°C under thin snow cover. In areas with a short growing season, seeding should be done in late August or early September. Where the growing season is longer, it should be done in late September and early October. Reproductive development is initiated after exposure to temperatures of 1°-4°C for 20 - 40 days in the spring. Shooting is optimum at 15°C, and grain maturation at 15°-20°C. Pollen can be killed by late spring frosts (-1° to -2°C), which may cause sterility in flowering plants. Flowering is optimal at 13° - 16°C.

WATER: Rye requires a minimum 40 cm of rainfall annually. The ability of the crop to continue growth at low temperatures increases its efficiency

in using moisture. Good yields occur in areas where annual rainfall is 50-75 cm. Rye has better tolerance to excessive soil moisture than wheat.

SOIL: The highest yields of rye are usually obtained on fertile, well drained soils. However, rye is more productive than other grains on infertile, sandy or acid soils. It is not suited to clays or organic soils. Adequate drainage is essential for good yields. Rye tolerates a wide pH range: minimum 4.5, optimum 5.5 - 7.0 and maximum 8.0.

REFERENCES: 19, 127, 128, 135, 154, 157

Triticum X *Secale* -- triticale

GENERAL: Triticale is receiving growing attention as a commercial crop. Specific studies concerning its climatic requirements, however, are rare. It is derived from a cross between wheat and rye, and therefore should have requirements similar to both. The current strains of triticale are not readily adaptable; changes in elevation, temperature, daylength, available moisture and nutrients and probably many other factors influence the crop's performance. Very little is known about the cultural practices required.

REFERENCE: 156

FAGOPYRUM spp. -- buckwheat; *F. ESCULENTUM* Moench -- buckwheat, common buckwheat, *F. TATARICUM* (L.) Gaertn. - Tartary buckwheat

LIGHT: There is no limitation by photoperiod.

TEMPERATURE: Buckwheat is adapted to a cool, moist climate. It is susceptible to cold and is killed when temperatures drop much below freezing. About 70 - 85 days are required from seeding to average maturity. Minimum soil temperature for germination is 9° - 11°C and optimum is 15° - 22°C. Better production is achieved during cool, humid summers. Flowering begins 4 - 6 weeks after seeding and continues until early frost. Harvest is difficult because seeds mature sequentially, and often one encounters both flowers and mature seeds on the same plant. Development is best under cool, humid conditions; poor flower fertilization occurs in warm, dry circumstances and yields are reduced by warm, rainy conditions at flowering. Buckwheat is sensitive to late spring and early fall frosts. It should be harvested before a killing frost as such exposure causes the seeds to fall off readily. Buckwheat needs 1800 to 2160 degree-days (42°F) to reach average maturity.

WATER: This crop requires a minimum 60 cm of rainfall annually. It is moderately tolerant of dry periods.

SOIL: This crop is well suited to deep, well-drained, sands and sandy loams with a pH of 5.5 - 7.0, but is also exceptionally tolerant of most infertile soils. Vegetative growth flourishes at the expense of grain production on fertile soils and lodging becomes a problem. Buckwheat is not suited to poorly drained and clayey soils.

GENERAL: Tartary buckwheat is grown in eastern Canada, but not in the west where it is classed as a weed. It will produce a better crop on poor soils than any other "grain."

REFERENCES: 91, 106, 133, 135, 137, 154, 157

SPECIAL CROPS

BETA VULGARIS L. -- sugar beet

LIGHT: There is no limitation by photoperiod, but the crop grows best under high light intensity. Sunshine is as important as temperature at the end of the growing season for good yields and maximum sugar content.

TEMPERATURE: This annual is suited to warm, sunny climates. Temperatures should be above 7 C to assure germination and prevent rotting in the soil. Germination and emergence occur within 9 - 10 days at temperatures of 9° - 10°C, and within 6 - 7 days at 15°-21°C. Young plants are susceptible to insects and disease.

This plant requires a growing season of 160 - 190 days from seeding to maturity, and a frost-free period of at least 130 days. About 2500 degree-days (42°F) are required to reach adequate maturity. Early development of the leaf canopy is essential to obtain good yields. Optimum temperatures for photosynthesis are 22°-38°C, depending upon the stage of development. The production of sugar correlates highly with heat and sunshine throughout the growing season.

The sugar beet is very sensitive to cold temperatures (-3°C or lower) at the emergence stage. Once above ground and somewhat conditioned, the plants become very hardy, tolerating cold temperatures of -4°C to -5°C without injury. The normal progression of spring temperatures, especially those approaching a daily average of 16°C, induces strong growth. Crop growth in late June, July and August is heightened by mean daily temperatures of 21°C or slightly higher; growth decreases with extremely high summer temperatures.

Fall temperatures are critical because of their profound effects on sugar storage. Under cool, sunny days and frosty nights of

late September or October, growth is checked but photosynthetic activity and storage of sugar are augmented. Sucrose levels rise until frost destroys the foliage. The levels may reach 15 - 18 per cent under the best conditions.

Premature bolting occurs when young plants are exposed to cool temperatures of 4° - 10°C, but subsequent warm periods may nullify previous effects of a short exposure to cold. The percentage of plants bolting increases with the length of the cold period (10 - 25 days) and varies between cultivars.

WATER: Sugar beets require 45 - 70 cm of water during the growing season. Distribution of rainfall is also important; excessive rain delays planting in the spring causing yield reduction, and excessive rain in the fall reduces sugar content and makes harvesting difficult. Sugar beets need 200-300 liters of water to produce a kilogram of dry matter. Adequate soil moisture is important to sustain root development after emergence; water shortages delay leaf development. A regular water supply during summer is necessary to maintain high photosynthesis rates.

SOIL: This crop can be grown on many soils but it is best suited to deep, well drained, fertile loams. Spring soil conditions are important because germination and emergence require moderate soil moisture. Sandy loams with high organic matter levels are very suitable; poorly drained, clayey soils should be avoided. Sugar beets require a high fertility level and pH should be maintained at 6.0 - 7.0.

REFERENCES: 7, 8, 9, 40, 41, 42, 43, 45, 46, 47, 117, 121, 122, 137, 154, 157, 158

SOLANUM TUBEROSUM L. -- potato

LIGHT: Potatoes show a remarkable response to day length. There is an increase in aerial stem elongation as the photoperiod increases, whereas short days induce tuberization. Yields are higher under high light intensity.

TEMPERATURE: This annual is suited to regions north of the 21°C isotherm for July. Germination and emergence are slow at 7°C; rapid emergence occurs when soil temperatures are above 12°C. The optimum soil temperature varies with stage of growth; rapid development of young sprouts occurs at 23°C, but later growth is best at 18°C. Injury from *Rhizoctonia* on the growing points of young shoots underground occurs mainly at temperatures below 20°C, with damage at 12°C being most serious. Above 20°C, rapid development of the growing point, together with retardation of *Rhizoctonia*, permits the tips of the young shoots to escape injury.

High soil and air temperatures are detrimental to normal plant development. Growth rate and yield are better in areas where temperatures during the warm months do not exceed 18° - 20°C. Optimal temperatures for tuber initiation and formation are 15°-22°C, depending upon the variety. Optimal conditions to maintain maximum growth rate for tubers are 20°C at daytime and 14°C at night. Growth of leaves and tubers decreases at 20° - 29°C and tuber formation is inhibited above 29°C. Leaves are destroyed by frost at -1°C. The progressively lower tuber yields at higher temperatures are due to a reduction in the synthesis of surplus carbohydrates over that consumed in respiration. Potatoes grown for chips should be harvested before soil temperature decrease to 7° - 10°C. A growing season of 85-140 days is required varying with cultivars and regions.

WATER: Water supply must be plentiful and regular for uniform and steady growth, particularily from tuber formation to maturity. Potatoes require a minimum 25 cm of water during the growing season. Ideally, plants should receive 20 - 30 mm every week during the growing season. Water shortages during July and August are a limiting factor in southern Ontario.

SOIL: This plant is suited to deep, fertile, well drained soils, with high organic matter levels and good water holding capacity. Loams and sandy loams are excellent because they warm early in spring, ensure good growth and tuber appearance, and are easily cultivated. Organic soils are suitable, and sandy soils are used also. Excessive soil moisture is not tolerated. Potatoes are grown on mildly acid soil (pH 4.8 to 6.8), the optimum pH being about 6.5.

REFERENCES: 20, 21, 91, 93, 111, 121, 122, 125, 154, 157, 169

NICOTIANA TABACUM L. -- tobacco

LIGHT: Under Canadian conditions the crop is insensitive to photoperiod. High light intensity is desirable.

TEMPERATURE: This annual is suited to different climates. In northern latitudes warm summer days and cool nights are most desirable. Tobacco seedlings must be reared to proper size in cold frames or hotbeds for 6 - 10 weeks before being set in the field. Germination and growth are slow at 10-15°C, optimal at 24-27°C and terminate above 35°C. The plant is not cold-tolerant and is seriously injured by frosts at -3°C. In cooler climates tobacco requires a frost-free period of 100 - 120 days from transplanting to full maturity. Transplanting should occur when danger from frost is over, but late planting may result

in injury from fall frost. Growth rates in the field are low at 15°C and optimal at 20-28°C. Leaves are injured above 38°C.

WATER: Sufficient rain is important during transplanting. Tobacco requires an ample and well distributed water supply for normal, rapid growth in the field. Areas best suited for tobacco receive 37-75 cm of rain during the growing season. This plant is very sensitive to inadequate drainage or waterlogging. Tobacco can tolerate lack of precipitation during the growing season if there are good soil moisture reserves.

SOIL: Tobacco can be grown on a wide range of soils. The quality of tobacco depends on an interaction between soil conditions and weather. Sandy soils with low organic matter, low water holding capacity and low fertility give large, thin leaves with weak aromas. Plants produced on clayey soils have smaller, darker leaves with a strong aroma. Tobacco is best suited to deep, well drained, very fertile sandy loams and loams. Acid soils with a pH 5.0 - 6.0 are excellent for production. Clayey and poorly drained soils should be avoided.

REFERENCES: 18, 91, 134, 137, 154, 157, 169

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